Textile antenna systems for positioning and off-body communication

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Outline

- Wearable textile systems:
  - Reliability concerns
  - Energy-efficiency concerns
- MIMO techniques for off-body communication
  - Reliability versus energy-efficiency
  - Space-time coding versus beam forming
- Integrating energy harvesters on textile antennas
  - Solar-cell PIFA antenna
- Robust wearable antennas for GPS/Galileo positioning
  - Providing stable performance in adverse conditions
- On-body wearable repeater as relay for implants
  - In-to-out body communication in an endoscopy application
- General conclusions

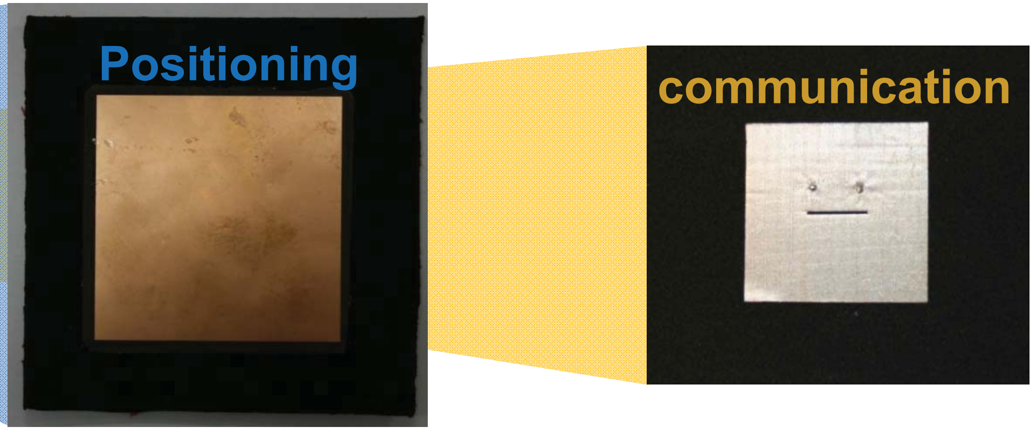
Textile antenna systems

Off-body communication with mobile command post: WiFi/LTE

Positioning via GNSS: Galileo/GPS/Glonass

A garment as antenna platform

- Exploit large area in garments
  ➔ efficient **flexible/wearable multi**-antenna system

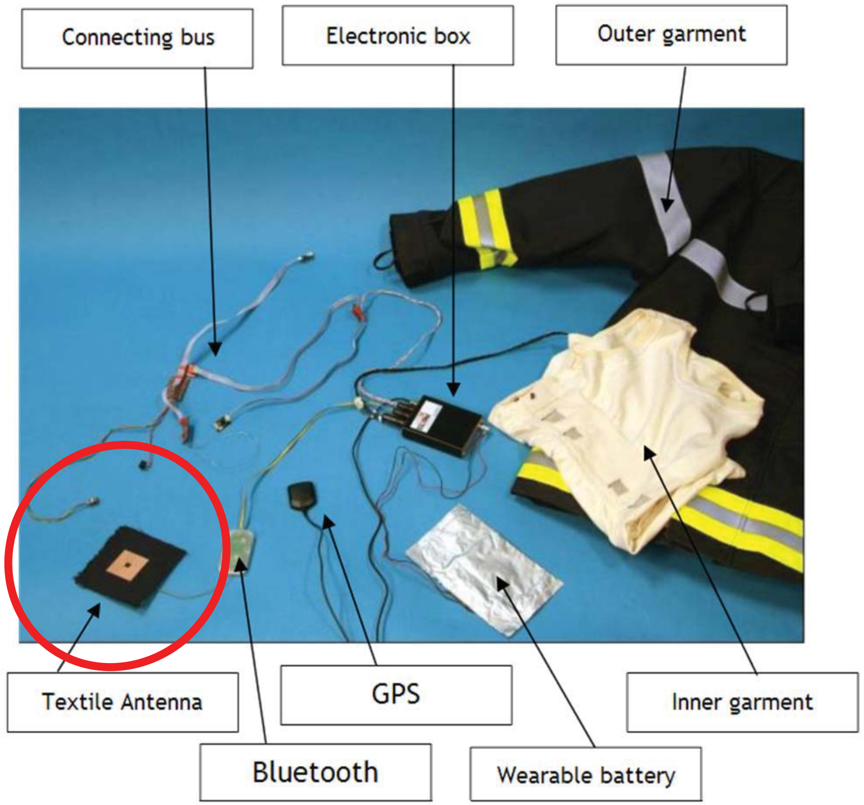


Realisation of reliable off-body links

Design requirement	*Issues*	*Required properties*
Robust wearable antennas	Bending, wrinkling Body absorption Variable humidity	Low-profile, light-weight Comfortable, breathable Stable high performance
Reliable off-body communication link	Fading Body-shadowing	Quality independent of position and posture

Textile systems: reliability

- First-generation textile system



- Many modules connected by wires
  - Expensive
  - Many weak links electronics ⇔ textiles
  - Maintenance???
    - washability?

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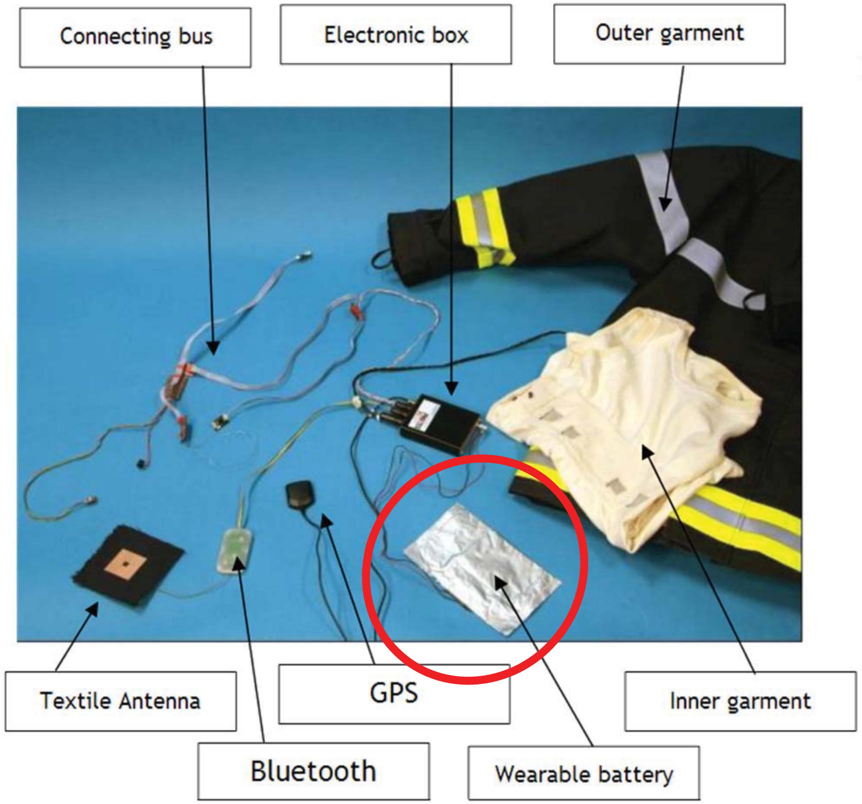
Textile systems: energy supply

- First-generation textile system



- Battery remains an issue
  - Reliability
  - Capacity
  - Weight/Flexibility
  - Frequent recharging
  - Maintenance???
    - washability?

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Future textile systems

- Reliable
  - Ad-hoc network of textile antenna modules
    - Compact, with integrated transceiver, energy supply/management, sensors, …
    - Wirelessly interconnected
    - Washable by applying a TPU coating
- Energy-efficient + autonomous
  - Designed for minimal energy consumption
    - Energy-efficient MIMO techniques
  - Integrated energy harvesters

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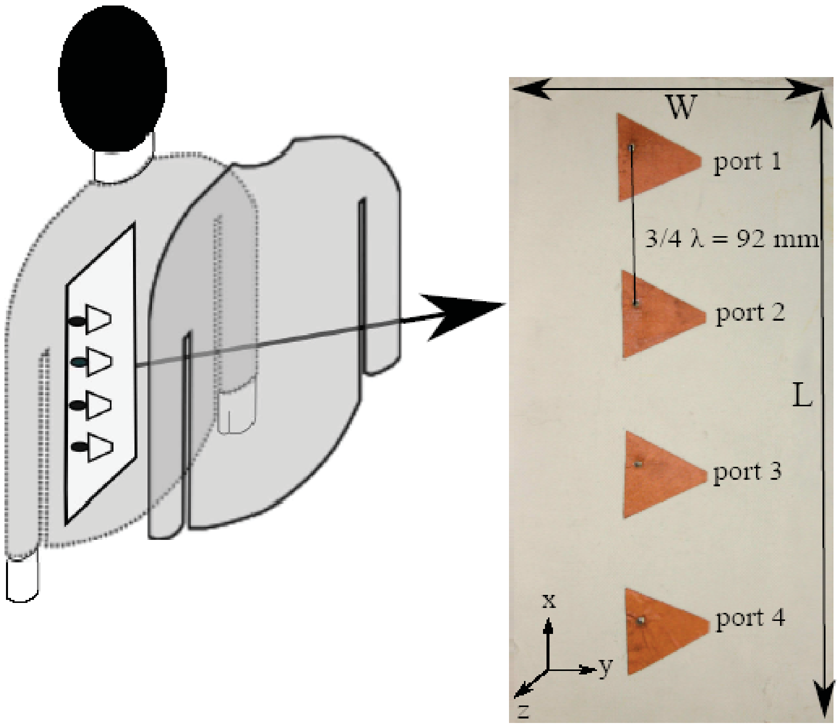
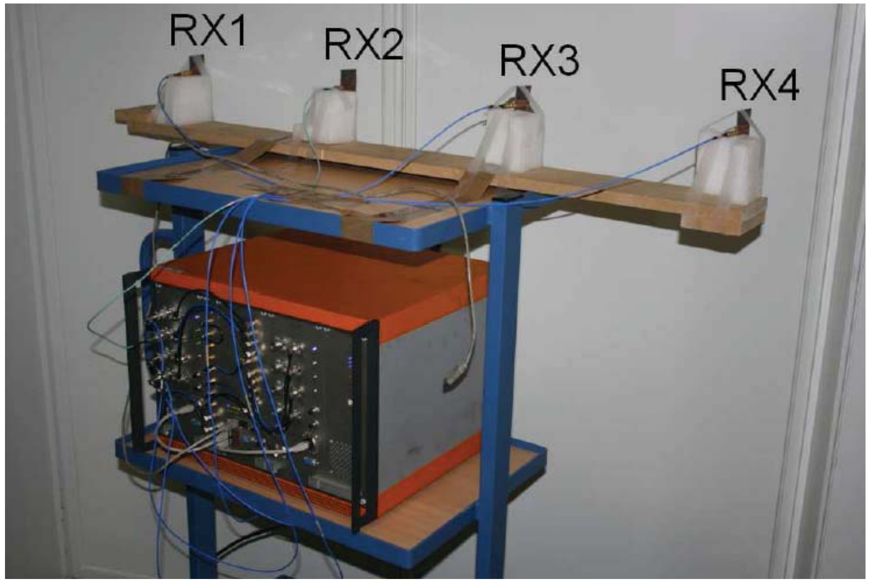
Static beamforming

- Motivation: reliability vs. energy-efficiency
  - Why static zero-elevation beam forming?
    - Absence of channel information feedback
    - Concentration of transmit power towards receiver on the same floor
    - Low-cost implementation compared to space-time coding
  - Beam forming versus space-time codes in equal propagation conditions
    - Measurement in indoor environment

Experimental setup





- Body-worn vertical textile array for space-time coding and beam forming
- Diversity receiver with maximal ratio combining
- Space-time coding and beam forming within each transmit frame

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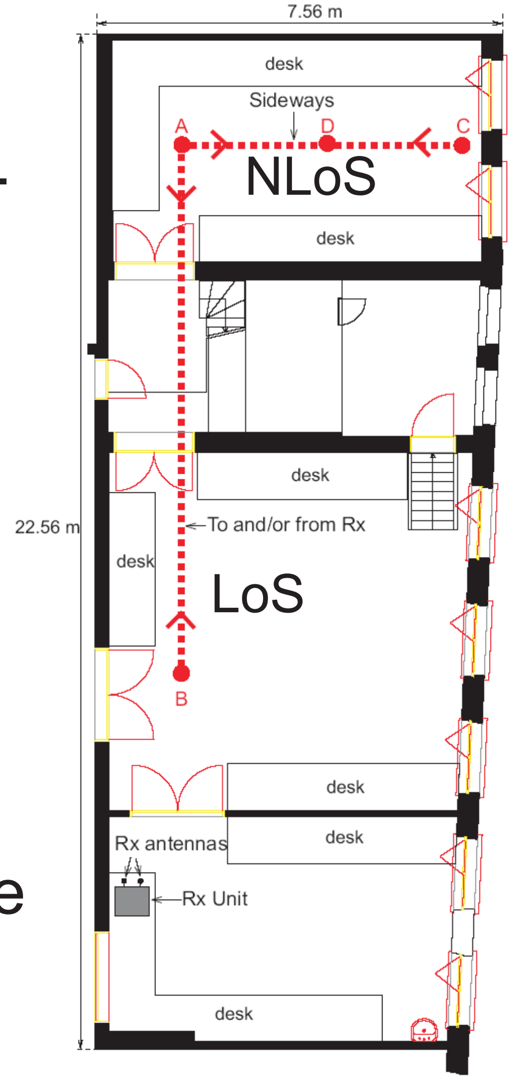
Propagation environment

- Indoor measurement environment
  - Line-of-sight (LoS) as well as non line-of-sight propagation (NLoS) paths
  - Solid brick walls block direct signal paths
  - Office equipment causes shadowing
  - Moving people cause channel variability
- Beam forming in this environment
  - Low-elevation signals provide higher average SNR at receiver
  - Diversity needed at receiver to mitigate multipath signal variation



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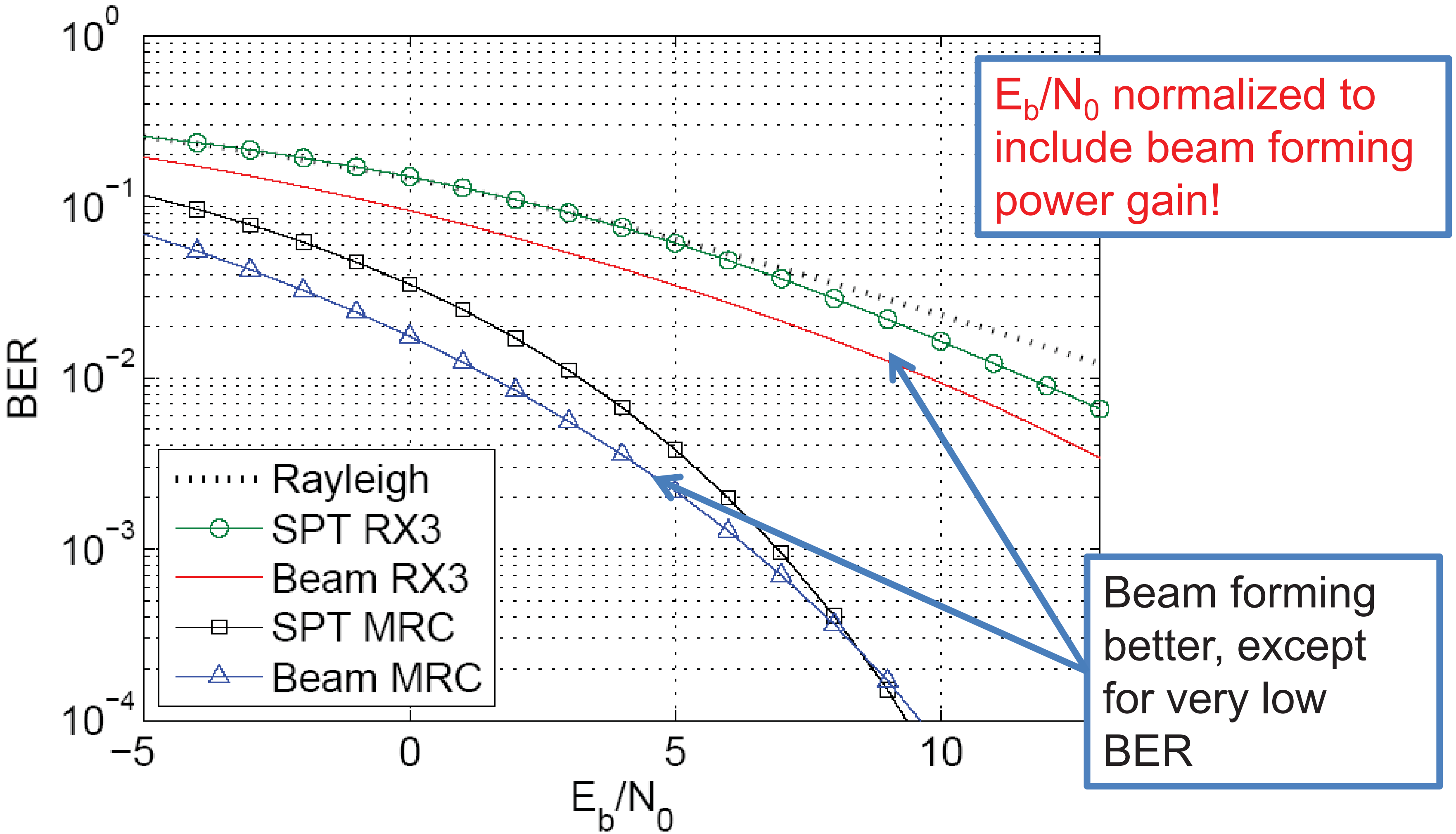
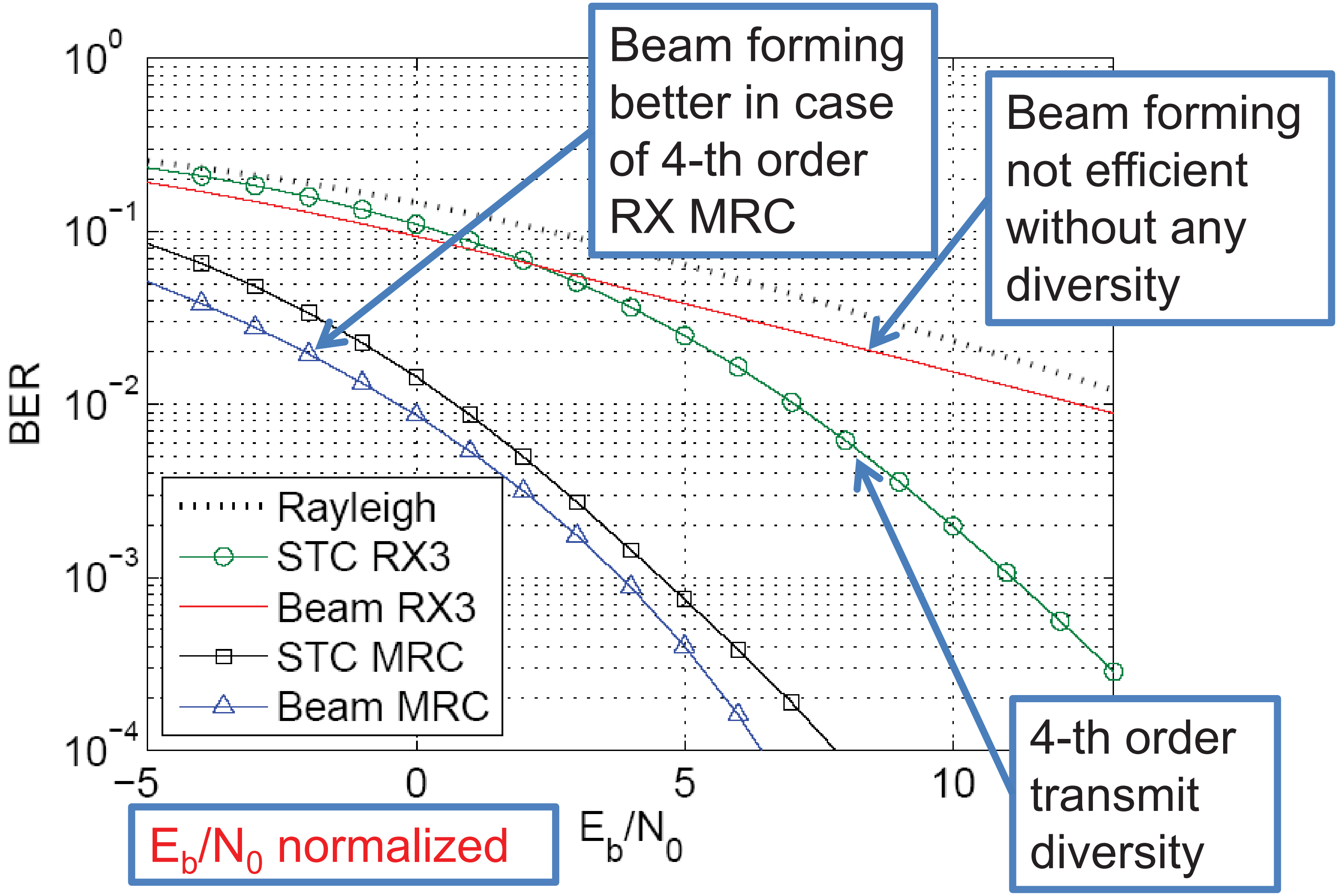
LoS BER characteristics



(TX array gain included: equal total transmitted energy per information bit $E_{b,tr}$)

SPT: space-time coding MRC: maximum-ratio combining

NLoS BER characteristics



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Integration of energy harvesters

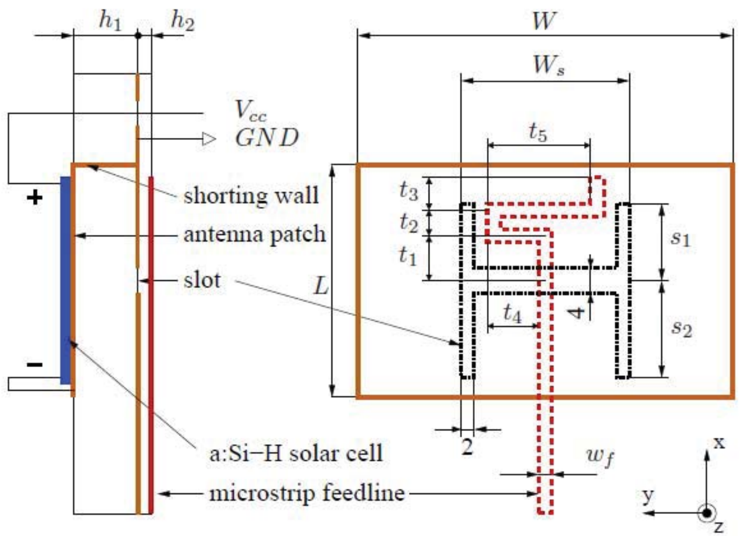
Wearable solar patch antenna

- Antenna specifications
  - $|S_{11}| < -10dB$, 902MHz-928MHz
  - Low profile
    - antenna thickness vs. bandwidth performance
  - No soldered RF connections
  - Robust operation in proximity human body
  - Minimize bulk power absorption
  - Compatible with solar cells
    - Small antenna vs. solar cell area
  - Based on flexible and breathable materials

→ Aperture-coupled shorted patch antenna

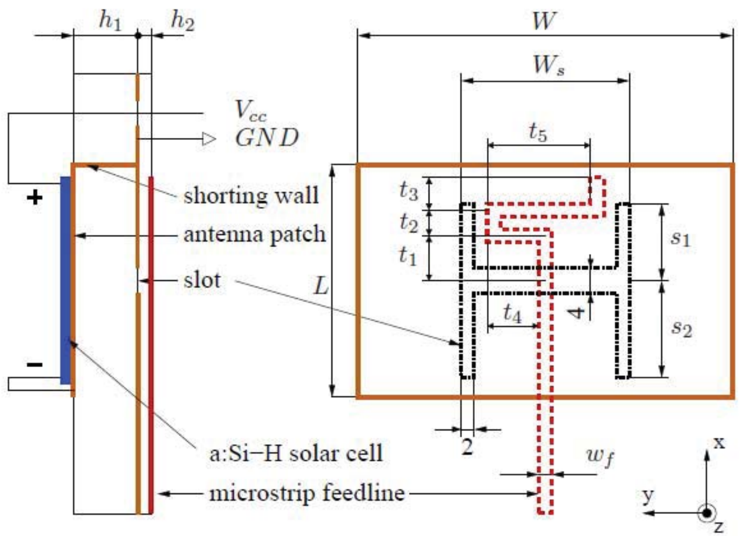
Wearable solar patch antenna

- Antenna topology
  - Shorted patch (λ/4)
  - Available area for solar cells (W*L)
  - Easy RF, DC connections
  - Meandered feed line
  - Aperture: H-slot
    - Maximize feed coupling
  - Active circuitry located beneath ground plane
    - Minimize parasitic coupling



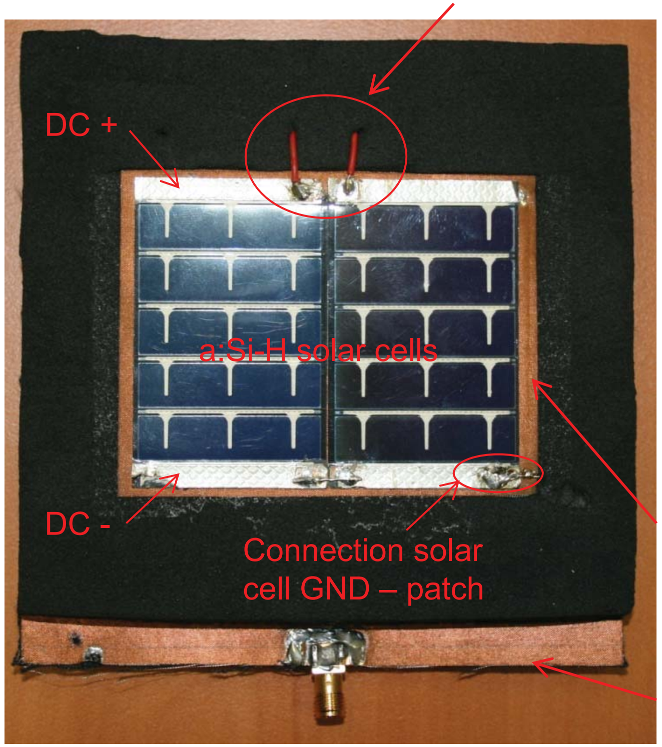
Wearable solar patch antenna

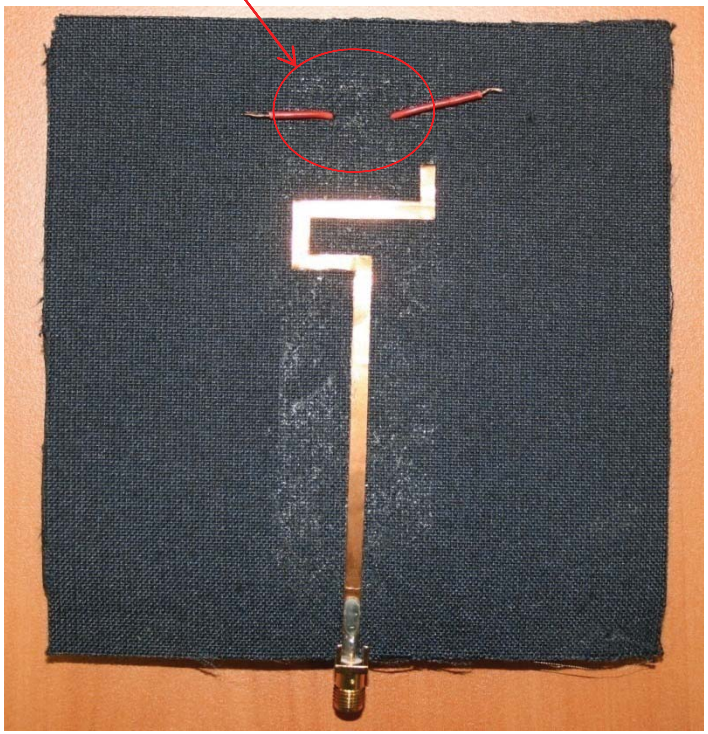
- Antenna materials
  - Antenna substrate:
    - Protective polyurethane foam
    - h_1 = 10mm
    - ε_r = 1.16, tanδ = 0.010
  - Feed substrate
    - 2 layers of textile aramid
    - h_2 = 0.95mm
    - ε_r = 1.97, tanδ = 0.020
  - Ground plane, shorting wall and patch
    - Flectron: copper-coated nylon fabric
    - R_s = 0.1 Ω/sq
  - Feed line = copper foil



Wearable solar patch antenna

- Solar cell integration
  - parallel connection
  - Active solar-cell area = 50mm x 37 mm per solar cell



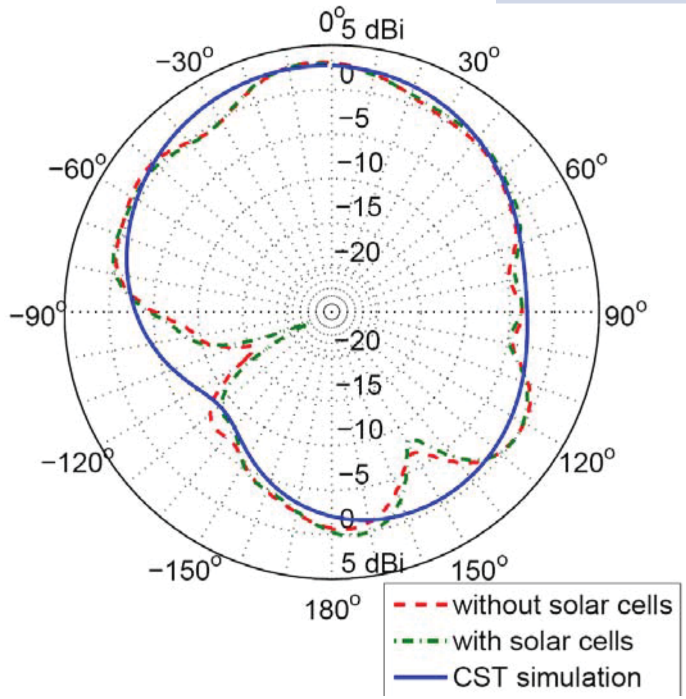


Effect solar cells on antenna radiation

- Impedance bandwidth: 48MHz@915MHz ISM band
- Free-space gain results

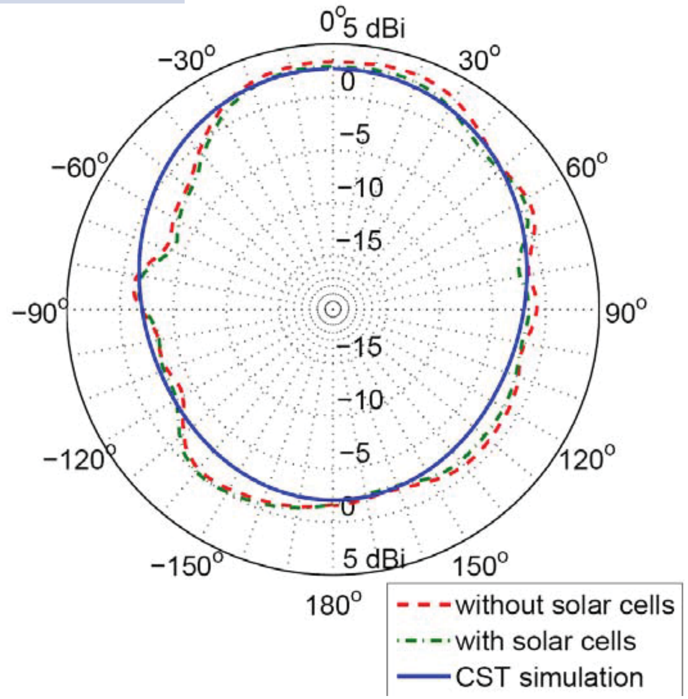
	measured	simulated
Max. gain	3 dBi	2.7 dBi

XZ- plane



915 MHz

YZ- plane



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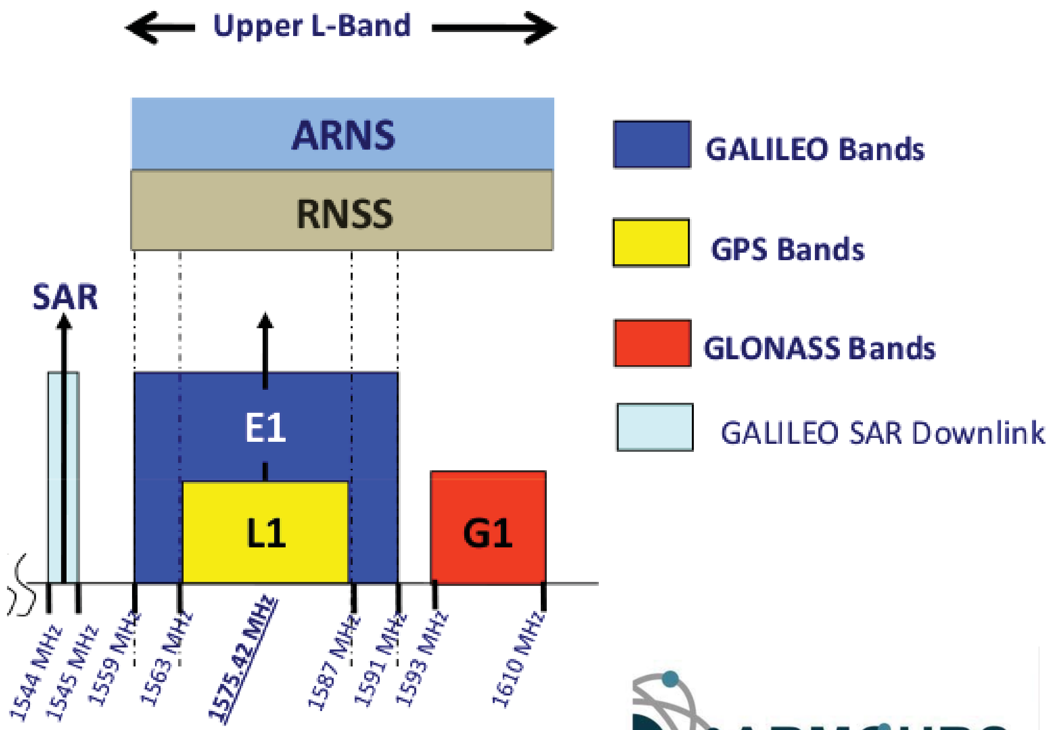
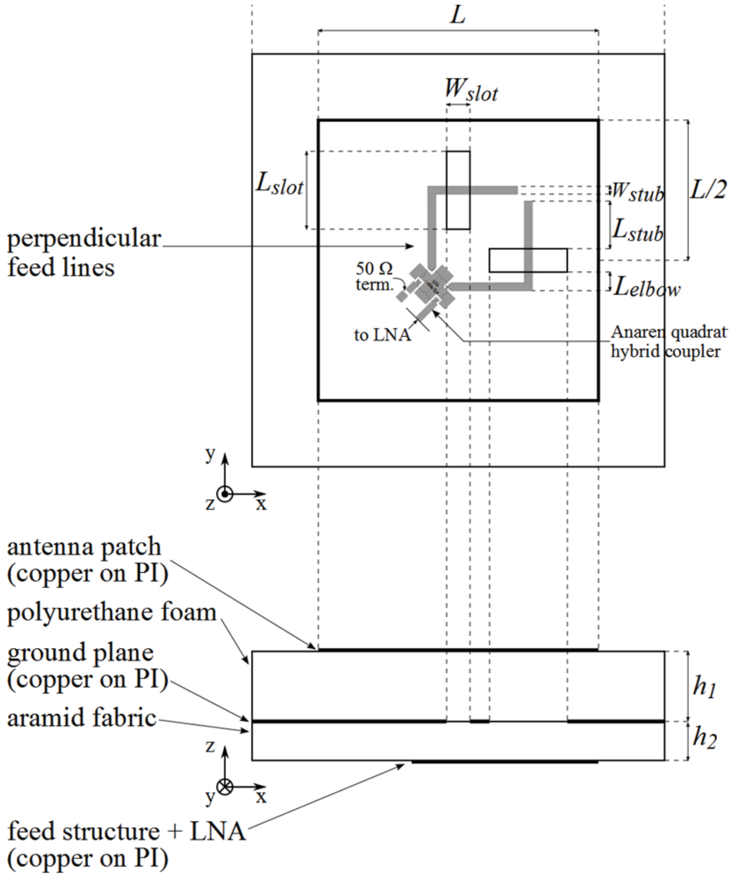
Wearable GNSS/Iridium antenna

- Broadband active antenna in terms of impedance and axial ratio matching





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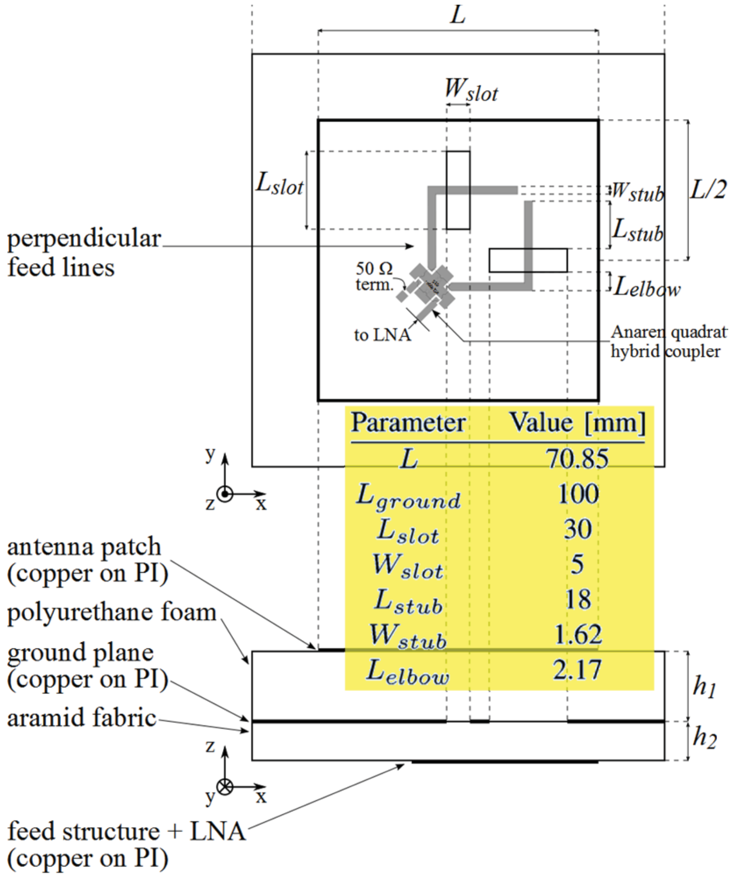
Wearable GNSS/Iridium antenna

- Broadband active antenna in terms of impedance and axial ratio matching
  - antenna substrate
    - polyurethane foam
  - feed substrate
    - aramid fabric
  - dual feed with hybrid coupler Anaren XC1400P
    - provides robust matching and wideband circular polarization
  - active receive antenna
    - Maxim MAX2659 chip LNA



Parameter	Value [mm]
L	70.85
L_{ground}	100
L_{slot}	30
W_{slot}	5
L_{stub}	18
W_{stub}	1.62
L_{elbow}	2.17

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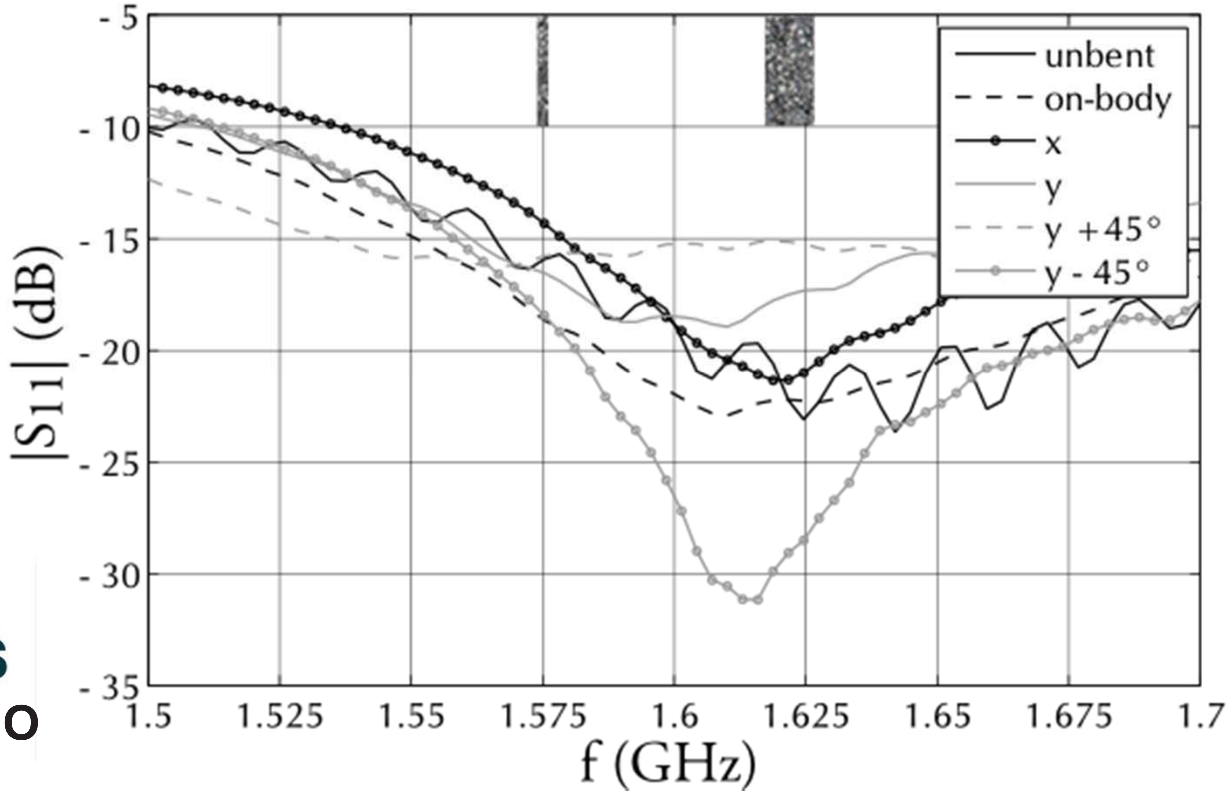
Wearable GNSS/Iridium antenna

- Passive antenna: impedance matching



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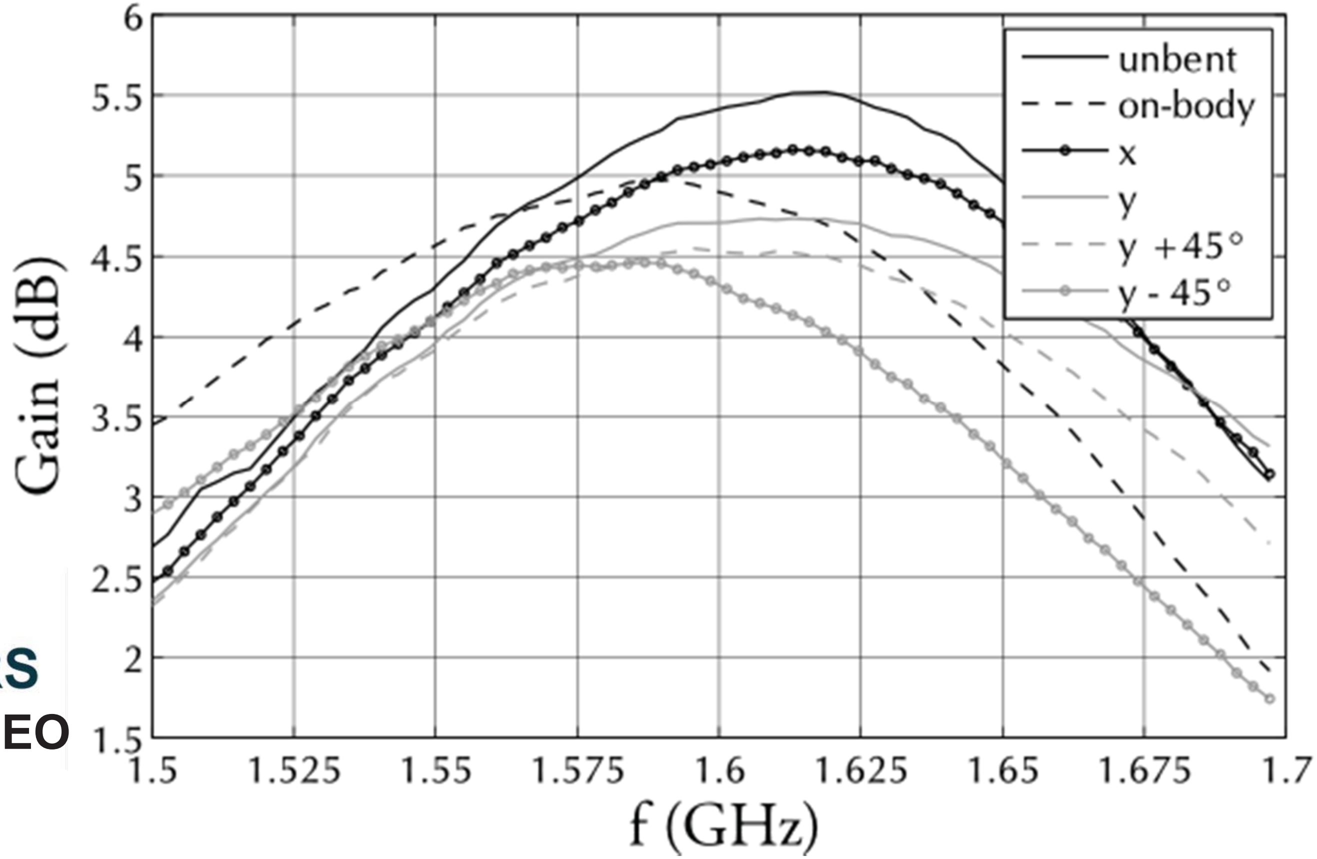
Wearable GNSS/Iridium antenna

- Passive antenna: Gain



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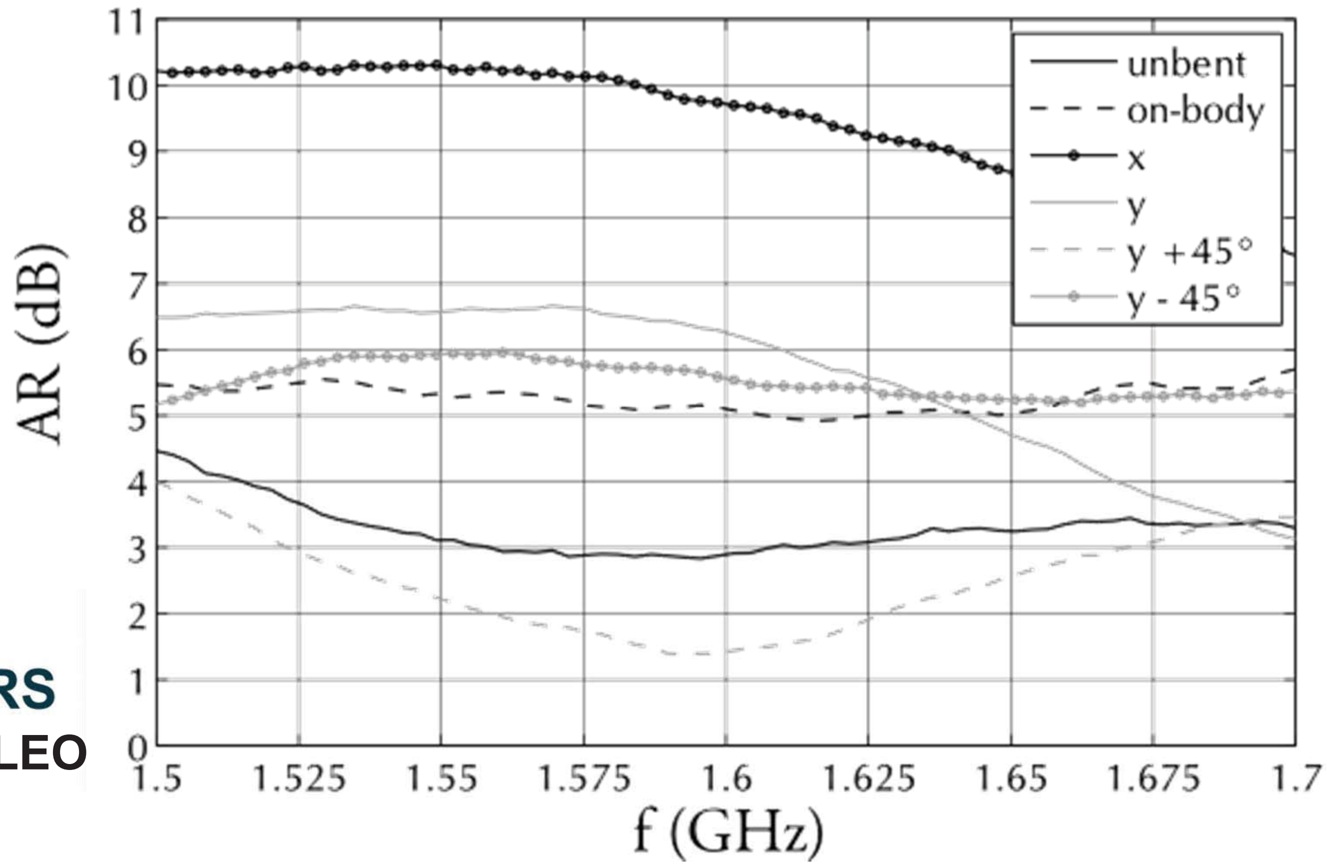
Wearable GNSS/Iridium antenna

- Passive antenna: Axial Gain



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Wearable GNSS/Iridium antenna

- Main figures of merit

	Passive antenna	Active antenna
Gain (dBi)	5.2	25.1
3 dB beam width	66°	68°
Axial ratio (dB)	2.476	1.866
3 dB axial ratio beam width	78°	106°
Matching bandwidth (free-space)	288 MHz (1.512 GHz – 1.8 GHz)	340 MHz (1.36 GHz – 1.7 GHz)
Axial ratio bandwidth (free-space)	52 MHz (1.558 GHz – 1.61 GHz)	183 MHz (1.517 GHz – 1.7 GHz)

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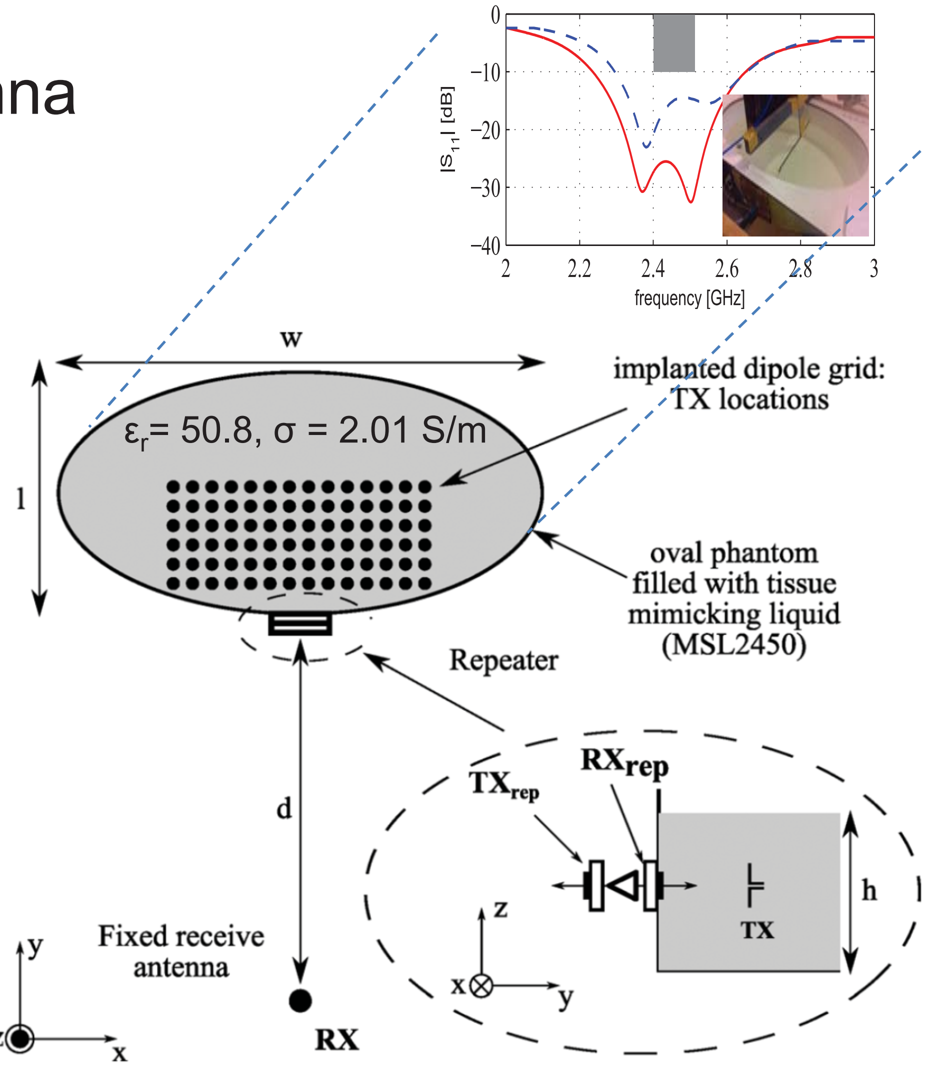
On-body wearable repeater antenna

- Wearable repeater antenna
  - Relay:
    endoscopy capsule
    (implanted dipole)
    ⇳
    remote base station
    (RX)

1. textile receive antenna (RX_{rep}) matched to body
2. amplifier
3. textile transmit antenna (TX_{rep}) matched to free space



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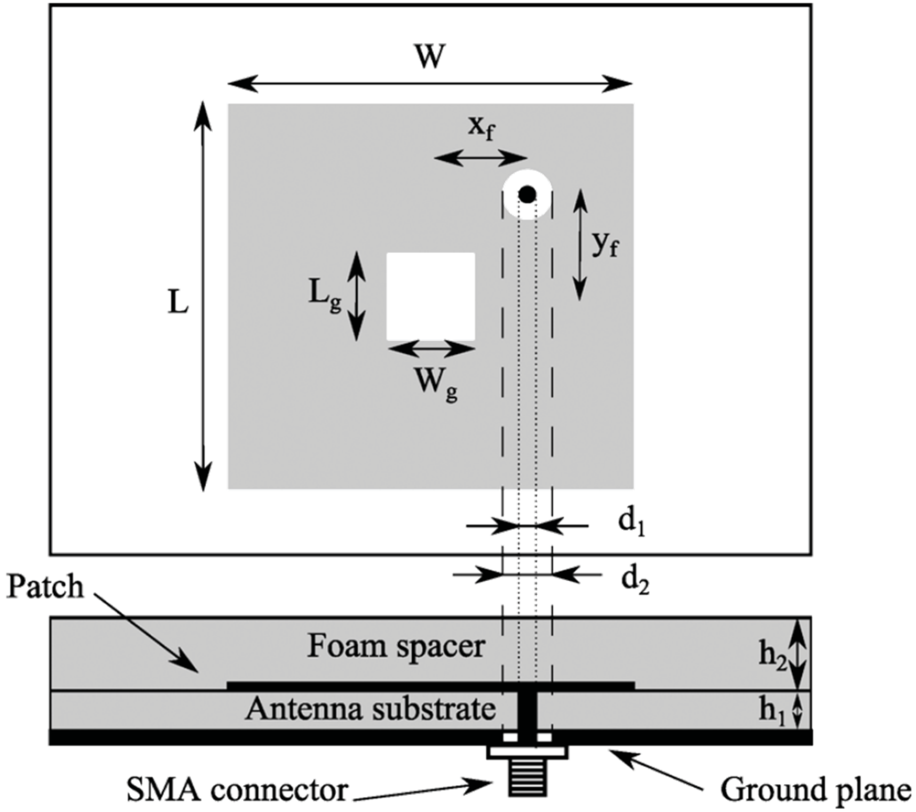
Repeater textile receive antenna

- Robustly matched to body
- Foam substrate
- Electrotextile
  - Ground plane
  - Antenna plane
- Foam spacer
  - stabilizes bandwidth when deploying antenna on different body parts



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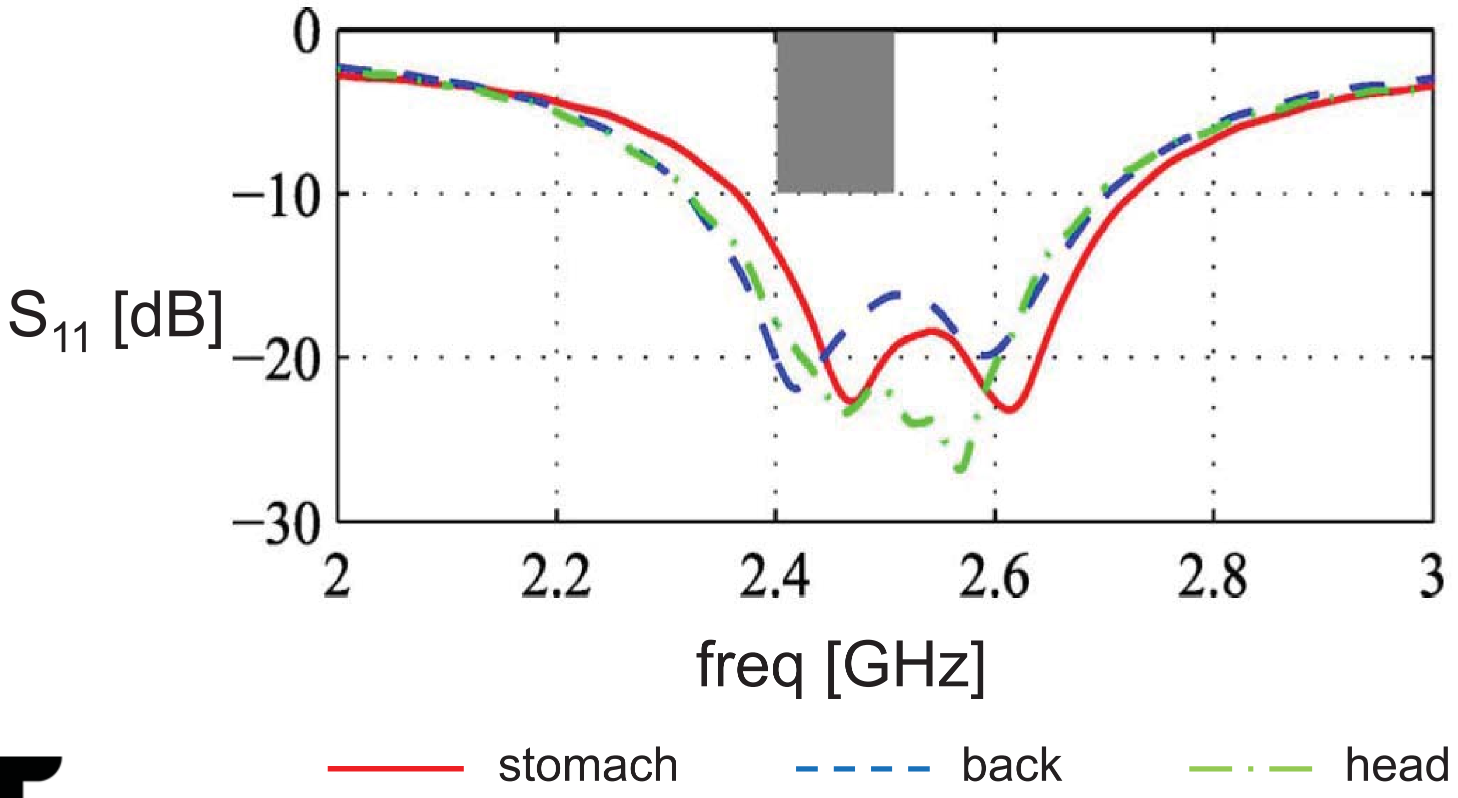
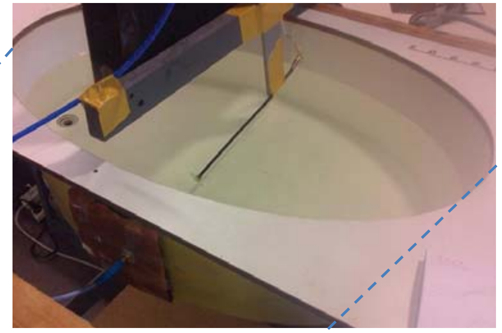
Repeater textile receive antenna

- Reflection coefficient when deploying antenna on different body locations

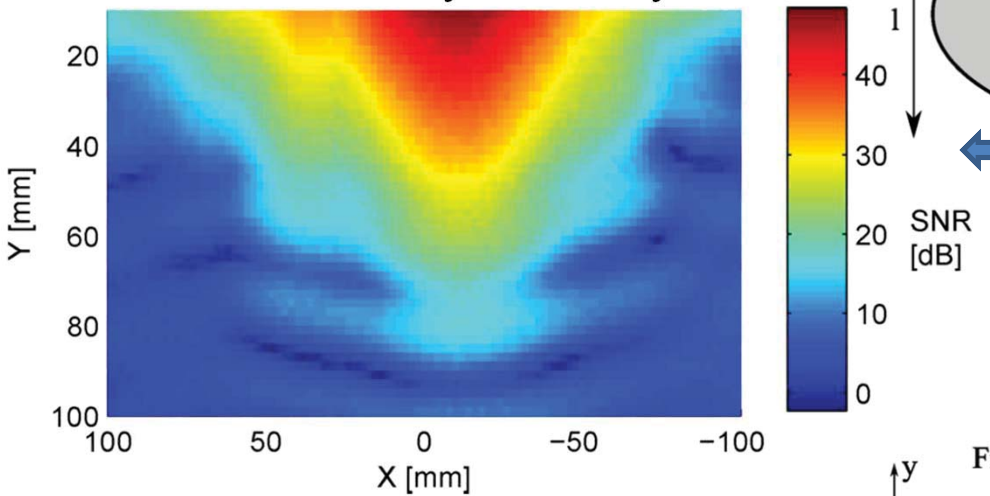


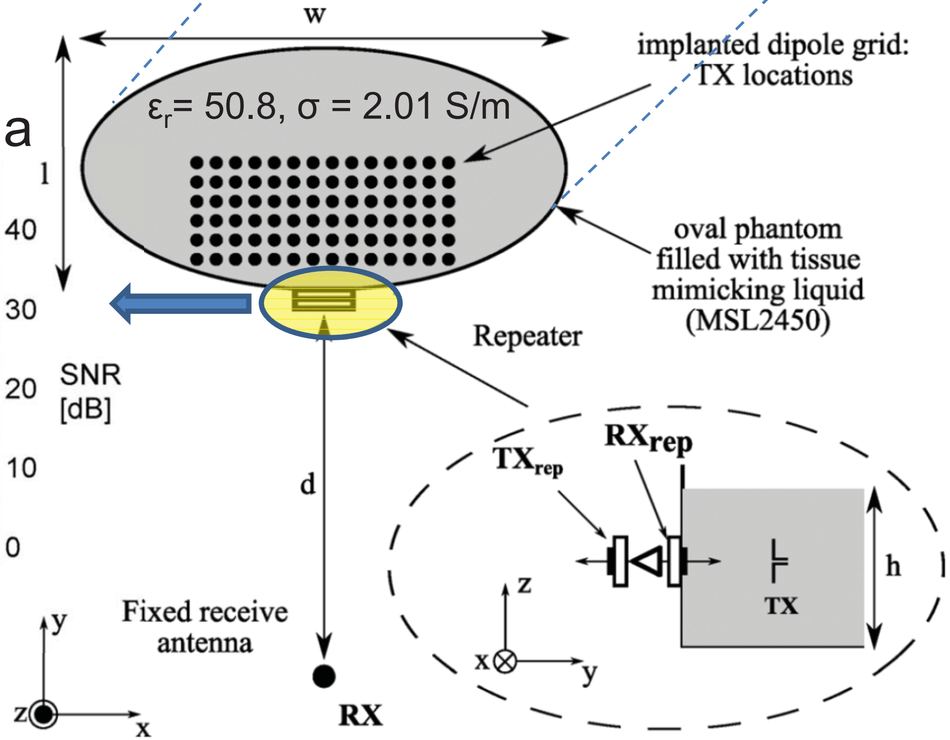
On-body wearable repeater antenna

- implant transmit power 10 mW, 2Mb/s QPSK test transmission
- average SNR at RX,
  without repeater: 8dBi
- average SNR at repeater: 30.1 dB



SNR received by on-body antenna





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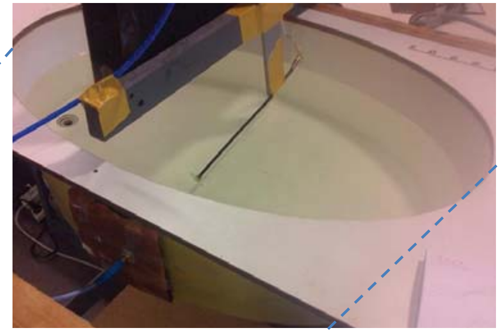
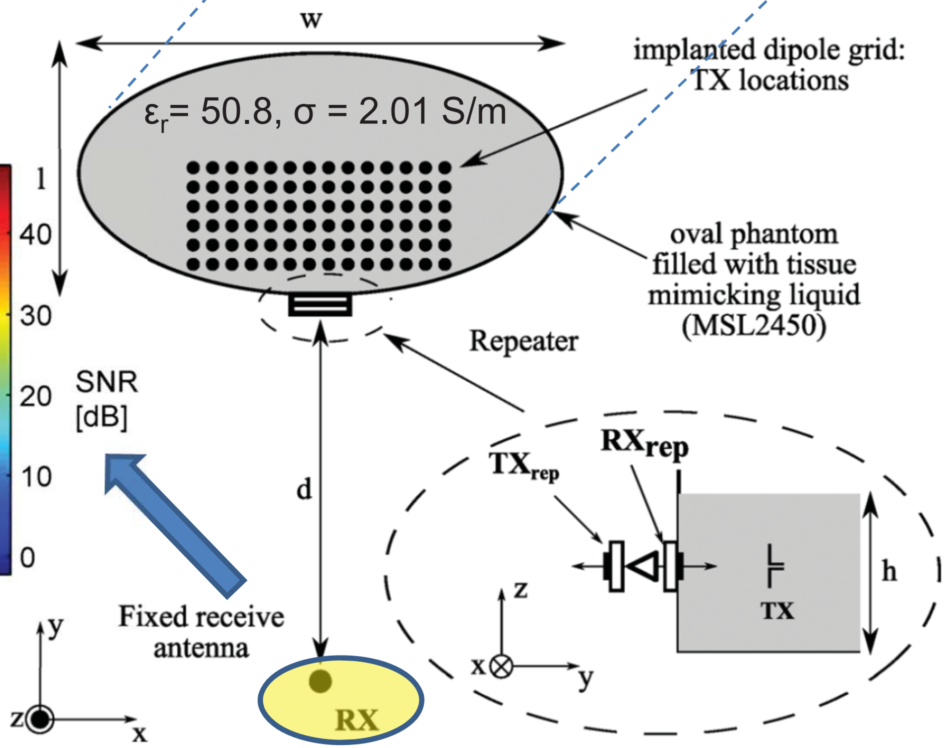
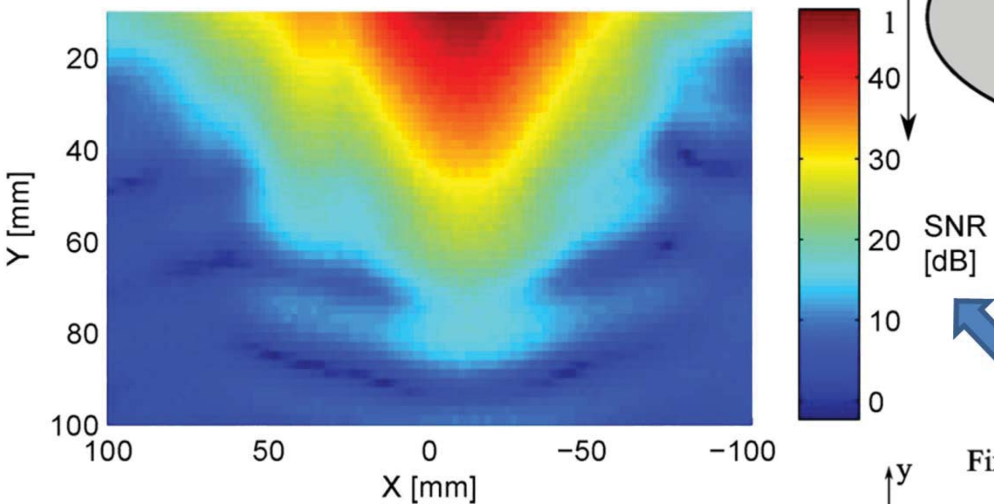
On-body wearable repeater antenna

- implant transmit power 10 mW
- Repeater with analog amplifier 4.38dB gain
- average SNR at RX: 33 dB





SNR received at RX



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General conclusions

- Challenges for reliable body-centric communications
  - Mechanical robustness
    - Avoid fragile links such as vias
    - Build compact active antenna modules
  - Stable antenna performance
    - Account for adverse effects during design
    - Test prototypes in realistic conditions
  - Mitigating fading/shadowing in the propagation channel
    - Make use of body as a large platform to deploy a multi-antenna system
    - Use space-time codes for transmit/receive diversity